Risk analysis of public-private partnership waste to energy projects: a systematic literature review

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Abstract. Despite potential benefits, public-private partnership (PPP) waste-to-energy (WTE) projects face significant risks—technical, financial, environmental, and socio-political—that threaten their feasibility. Key risk factors include revenue uncertainty, government credit reliability, and public opposition. The study is designed as systematic literature review (SLR) with three-phase methodology: planning, conducting, and reporting. A total of 136 articles from 2014 to 2024 were included in the initial selection. After applying all the criteria from the review protocol, 19 final articles were retrieved. The review identifies financial, technical, environmental, and social risks and highlights the importance of advanced risk assessment models like the 2-Dimension Linguistic Environment and Cloud Model and Bayesian Analytics for better decision-making. Differences in risk perceptions among stakeholders—government, public, and private entities—are examined, emphasizing the need for collaboration and transparency. Effective management of financial and market risks, particularly in emerging economies, involves policy implementation, government guarantees, and comprehensive risk allocation frameworks. There needs to be cooperation, clear communication, and policy frameworks to manage these different concerns effectively, ensuring that PPP WTE projects succeed and remain sustainable.

1 Introduction

The increasing global emphasis on sustainable waste management and energy production has propelled the adoption of waste-to-energy (WTE) technologies, particularly within public-private partnership (PPP) frameworks. These partnerships leverage private sector expertise and investment to address the growing challenge of municipal solid waste (MSW) while simultaneously generating renewable energy.

Currently, the PPP financing model is extensively used for implementing WTE incineration projects. This approach addresses the limitations of public finances while capitalizing on the advanced production experience and management systems of the private

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sector. Many instances of WTE incineration projects have been developed under this model, including China's first WTE incineration plant, the Chongqing Tongxing WTE incineration plant, completed in 2005. The PPP model is utilized to address the financial limitations of the public sector by leveraging private sector expertise and management systems. This is particularly relevant for developing countries like China, where public financial resources may be insufficient to meet infrastructure needs. This model is particularly appealing in scenarios where public resources and expertise are limited, enabling the mobilization of private capital and innovation to achieve sustainable waste management solutions [1].

Despite the potential benefits, PPP WTE projects still has several risks that can undermine their feasibility and sustainability. These risks arise from various sources, including technical, financial, environmental, and socio-political factors. Technical risks, for example, involve challenges with the suitability of technology and operational performance, while financial risks include revenue uncertainty and potential overruns in construction or operating costs. Environmental risks can lead to pollution and subsequent public opposition, which is one of the most critical challenges as it can cause project delays or cancellations. Socio-political risks, such as government credit risk and decision-making processes, can undermine project stability and lead to failures. The complexity of these risks, coupled with the long-term nature and substantial investments required for PPP WTE projects, makes them particularly challenging to manage effectively [2].

A comprehensive understanding of risk dynamics in PPP WTE projects is critical for developing effective mitigation strategies. Furthermore, the integration of advanced risk assessment models has been proposed to better capture the fuzziness and randomness associated with risk evaluations [1].

This systematic literature review aims to elaborate existing research on the risk assessment of PPP WTE projects, focusing on the methodologies employed, the key risk factors identified, and the strategies recommended for risk mitigation.

2 Methods

The methodology for the research follows the three-phase approach of planning, conducting, and reporting a review, as proposed by Kitchenham (2007) [3].

2.1 Planning

The first phase involves planning the research question and review protocol to ensure thorough literature coverage. This includes defining the study's scope and formulating precise research questions.

The researchers defined the scope of the study and formulated research questions using the PICOC approach (Population, Intervention, Comparison, Outcomes, and Context), shown in Table 1. The research questions established are as follows:

RQ 1: What key risk factors most impact the feasibility and success of PPP WTE projects?

RQ 2: How effective are different risk assessment methods in identifying and reducing risks in PPP WTE projects?

RQ 3: What are the main differences in risk perceptions and management strategies among stakeholders in PPP WTE projects?

RQ 4: What are the best strategies for managing financial and market risks in PPP WTE projects in emerging economies?

Table 1. Summary of PICOC

Population	PPP Waste-to-Energy projects
Intervention	Risk Identification, Risk Assessment, Risk Analysis
Comparison	n/a
Results	Key risk factors, stakeholder risk perceptions , risk mitigation strategies, risk management frameworks.
Context	Challenges and opportunities in implementing PPP WTE projects to achieve sustainable solutions

The next step is to create the review protocol by setting inclusion and exclusion criteria to ensure that selected papers align with the research objectives. Papers are included if they focus on risk analysis in Public-Private Partnership (PPP) Waste-to-Energy (WTE) projects and are published as journal or conference papers between 2014 and 2024. These papers must also be written in English or Indonesian. Papers are excluded if they lack a specific focus on risk analysis or have incomplete records or presentation issues. This process ensures that the literature review remains relevant and contributes effectively to understanding risk management in PPP WTE projects.

2.2 Conducting

The search process for the paper is conducted by applying the stated inclusion and exclusion criteria. Full paper accessibility also restricts the search process. Initially, the search is carried out using the Publish or Perish (PoP) application. Two digital library are used, Scopus and Google Scholar. The search terms used are listed in the "search terms" subsection, and the sources of the publication papers are specified in the "data source" subsection. A total of 136 articles from 2014 to 2024 were included in the initial selection. After applying all the criteria from the review protocol, 19 final articles were retrieved.

When executing the search process, the search terms included were “waste to energy AND risk*”, “wte AND risk*, “wte AND risk* AND ppp”, “wte AND risk* AND public private partnership*”, “waste to energy AND risk* AND public private partnership*”, “waste to energy AND risk* AND ppp”, and “Pembangkit Listrik Tenaga Sampah AND risiko.

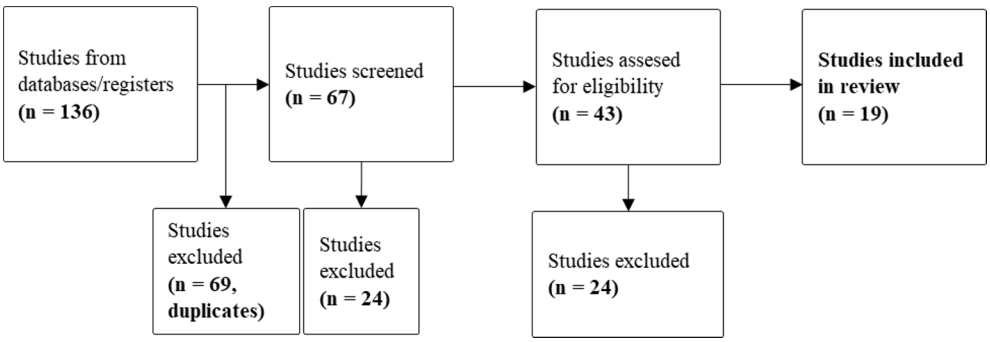

Fig. 1. PRISMA Flow Diagram

2.3 Reporting

This stage involves analyzing, presenting, and discussing data to answer the research questions and understand current risk assessments in PPP WTE projects, highlighting

specific research gaps. The findings emphasize the need for strategies that involve stakeholders and policy frameworks to improve risk management and ensure project success. By integrating insights from the literature, a clearer understanding of risk dynamics and stakeholder perspectives in PPP WTE projects is achieved, guiding future research and practical applications.

3 Result and Discussion

The results and findings of the review were begun by reporting how the papers were selected based on the predetermined criteria. Based on the data extraction and analysis, the research questions were then can be answered.

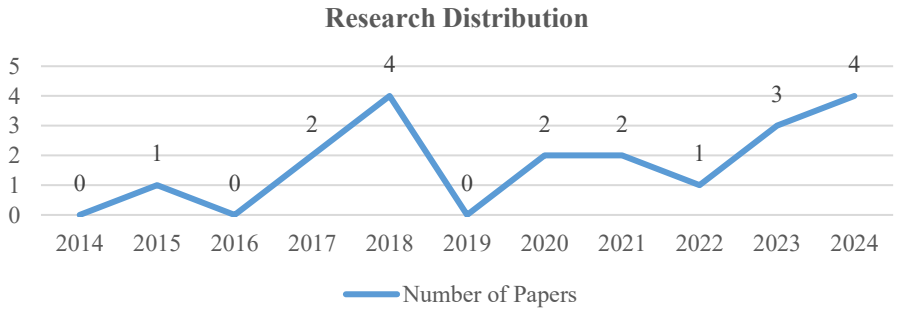

Fig. 2. Research Distribution from 2014 – 2024

3.1 Key risk factors of PPP WTE projects

WTE projects, especially those using PPP models, face several financial risks that can threaten their viability. Key risks include revenue uncertainties from fluctuating energy sales and inconsistent government subsidies, which impact financial health. Additionally, the potential for operating and construction cost overruns can strain budgets and reduce profitability, making financial management a critical component of project success[2,4–7]. Further complicating the financial landscape are government credit and payment risks; when government entities fail to meet their financial commitments or delay payments, it can disrupt cash flow and financial planning, necessitating robust management strategies to mitigate these risks [8–11].

Technical risks also play a crucial role in the execution of WTE projects. These risks are very associated with the potential failures of technology and equipment, which can lead to delays in project completion, increased construction costs, and operational performance issues. Moreover, if the technology fails to handle waste emissions, it can result in significant environmental pollution. The document underscores the interconnected nature of technical risks with other project risks, as technical failures can lead to broader financial and environmental challenges. To mitigate these risks, it is essential to implement effective risk management strategies, such as selecting reliable technology and conducting thorough testing and maintenance [4,8–11].

Environmental and social risks further complicate the landscape for WTE projects. Environmental risks are primarily due to the release of harmful pollutants during the incineration process, aggravated by the complexity of waste composition, which can include toxic substances. These risks cause threats to public health and safety and can lead to public opposition, potentially delaying or halting project implementation [2,8–11]. Social risks, particularly public opposition driven by environmental concerns, can significantly impact

project timelines and costs. The document emphasizes the importance of early public engagement, improved communication about the benefits and safety of WTE technologies, and transparency in decision-making to gain public acceptance. Effective management of these risks is crucial for the successful and sustainable implementation of WTE projects, highlighting the need for proactive stakeholder management and community engagement strategies [2,6,7,9–11].

Table 2. Key Risk Factors of PPP WTE Projects

Key Risk Factors	Author(s)	Results
Financial risk	Ghimirea et al. 2024; Wang & Zhang, 2017; Utama, 2020; Jie & Jie, 2024; Wang et al. 2024	Financial risks in PPP WTE projects include uncertainties in revenue from energy sales and subsidies, cost overruns, government credit and payment risks, all of which emphasize the need for effective management to ensure project success.
Technical risk	Ghimirea et al. 2024; Zhang & Wang, 2018; Sun et al. 2017; Cui et al. 2020; Liu et al. 2018	Technical risks in WTE projects, which can cause cost overruns, delays, and environmental pollution, must be mitigated through effective risk management strategies to prevent cascading financial and environmental challenges.
Environmental Risk	Zhang & Wang, 2018; Wang & Zhang, 2017; Sun et al. 2017; Cui et al. 2020; Liu et al. 2018	Environmental pollution risks from harmful emissions during incineration in WTE projects require effective management through proper technology, rigorous monitoring, and adherence to standards to mitigate public health threats and potential project delays due to public opposition.
Government decision-making risk	Wang & Zhang, 2017; Sun et al. 2017; Cui et al. 2020; Liu et al. 2018	Government decision-making risk, stemming from inexperience and inadequate planning, can significantly impact the success of PPP WTE projects by causing delays, increased costs, and public opposition, emphasizing the need for improved decision-making processes to ensure project feasibility.
Social risk, public opposition	Wang & Zhang, 2017; Sun et al. 2017; Cui et al. 2020; Liu et al. 2018; Jie & Jie, 2024; Wang et al. 2024	Social risk, notably public opposition due to environmental and health concerns, significantly impacts PPP WTE projects, necessitating early public engagement and transparent communication to mitigate delays and costs and ensure project success.

3.2 The effectiveness of different risk assessment methods

The conventional approach to risk analysis in PPP WTE projects primarily involves identifying, assessing, and managing risks using established methodologies. These traditional methods include techniques such as Monte Carlo simulation, fault tree analysis, fuzzy synthetic evaluation, and sensitivity analysis. These methods are well-known for their systematic processes but often treat risks in isolation, which presents challenges in integrating qualitative data or dealing with interrelated risks. These approaches often face limitations

due to their reliance on subjective judgments, lack of dynamic updates with new data, and insufficient handling of interdependencies between risks. These challenges highlight the need for more sophisticated methods to improve accuracy and effectiveness in risk management [1,6,8,12].

The 2-Dimension Linguistic Environment and Cloud Model represents an advanced method that combines linguistic variables and cloud models to address the inherent fuzziness and randomness in risk assessments. This approach improves how we express uncertainty by including both the risk level and the confidence in that assessment. This allows for a clearer and more detailed analysis of qualitative information. By effectively capturing the complexities of risk factors, this method provides a more accurate and reliable risk assessment, aiding in better decision-making and risk mitigation strategies [1].

Similarly, Bayesian Analytics improves risk probability estimation by integrating expert judgments with historical data, overcoming traditional methods' limitations. This approach offers more accurate risk occurrence probability estimations, helping decision-makers develop effective risk management strategies and allocate resources efficiently [13]. Additionally, the Hybrid Weight Methods and Weighted Multigranulation Fuzzy Rough Sets (MGFRSs) combine subjective and objective assessments for a balanced risk evaluation. This method handles the complexity and heterogeneity of information, avoiding mutual compensation among risk factors, and assists in selecting projects with the lowest risk profile, promoting sustainable waste management practices [12,14].

Table 3. Effectiveness of Different Risk Assessment Methods

Risk Assesment Methods	Author(s)	Results
Conventional approach	Wu et al. 2018; ; Wang & Zhang, 2018; Cheng et al. 2023; Jie & Jie, 2024	The conventional risk analysis approach involves systematic processes but faces limitations due to subjective judgments, lack of dynamic data updates, and insufficient handling of risk interdependencies.
The 2-Dimension Linguistic Environment and Cloud Model	Wu et al. 2018	This method enhances uncertainty expression by incorporating risk levels and confidence in assessments, allowing for detailed analysis and more accurate risk assessment to improve decision-making and mitigation strategies.
Bayesian Analytics	Wang & Zhang, 2018	Bayesian Analytics improves risk probability estimation by integrating expert judgments with historical data, offering a more accurate assessment than traditional methods and aiding in effective risk management and resource allocation.
The Hybrid Weight Methods and Weighted Multigranulation Fuzzy Rough Sets (MGFRSs)	Cheng et al. 2023	This method avoids mutual compensation among risk factors, enabling a comprehensive assessment that assists in selecting projects with the lowest risk profile, thereby promoting sustainable waste management.

3.3 The differences in risk perceptions and management strategies among stakeholders

In PPP WTE projects, stakeholders perceive risks differently due to their unique roles and interests. Governments focus on policy and regulatory risks, the public on environmental and health concerns, and private stakeholders on financial and operational risks in PPP WTE projects. For example, in China, government decision-making risk, legal, and policy risks are critical in WTE incineration projects. The government is concerned with ensuring regulatory compliance and maintaining social order, particularly given the potential for public opposition. In Egypt, the government's responsibility extends to managing land accessibility and social risks, which involves addressing public concerns and facilitating land acquisition. To mitigate these risks, governments focus on establishing supportive regulatory frameworks, engaging in public discourse, and ensuring transparency to foster public acceptance and stability [4,7,15,16].

The public's risk perception is predominantly centered around environmental and health impacts. Concerns about pollution, health safety, and the environmental consequences of WTE technologies like incineration are significant. In India, for instance, environment, health, and safety risks are common concerns across various energy-from-waste technologies. Public opposition often stems from fears of pollution and environmental degradation. To manage these risks, strategies such as transparent communication, adherence to environmental standards, and public engagement are crucial. These measures aim to build trust and acceptance among the public for WTE projects, addressing their environmental and societal concerns effectively [4,7,17].

Private stakeholders are primarily concerned with financial viability and operational risks. In Nepal, financial and market risks are perceived as the most critical by private entities due to uncertainties in revenue streams and investment returns. Similarly, in India, private stakeholders are concerned with financing, revenue, and waste collection risks, which directly affect the financial success of the projects. The private sector often advocates for incentives, risk-sharing mechanisms, and technological innovations to mitigate these risks. Effective risk management strategies involve negotiating clear risk allocation agreements, leveraging technological advancements to improve operational efficiency, and seeking governmental support to ensure a stable investment environment. Overall, these stakeholders have distinct perspectives on risk due to their different priorities and responsibilities in WTE projects. Collaborative strategies that address these diverse concerns are essential for the successful implementation of PPP WTE projects [4,16–18].

Table 4. The differences in risk perceptions and management strategies among stakeholders

Stakeholders	Author(s)	Results
Government	Ghimirea et al. 2024; Cao et al. 2022; Wang et al. 2024; Gad et al. 2024	Governments perceive policy, regulation, and social stability risks as critical, exemplified by China's focus on regulatory compliance in WTE projects and Egypt's management of land and social risks, both emphasizing supportive frameworks, public engagement, and transparency to mitigate these concerns.
Public	Ghimirea et al. 2024; Dolla & Laishram, 2021; Wang et al. 2024	The public's risk perception focuses on environmental and health impacts, with concerns about pollution and safety in WTE technologies, necessitating transparent communication, adherence to standards,

		and public engagement to build trust and acceptance.
Private	Ghimirea et al. 2024; Dolla & Laishram, 2021; Gad et al. 2024	Private stakeholders focus on financial viability and operational risks, emphasizing the need for incentives, risk-sharing, and technological innovations to mitigate uncertainties in revenue and investment returns.

3.4 The strategies for managing financial and market risks

In managing financial and market risks in PPP WTE projects in emerging economies, policy implementation plays a crucial role by creating a stable regulatory environment and offering government guarantees that reduce investment uncertainties. Understanding stakeholders' risk perceptions is vital for safeguarding investment decisions, as identified in a study conducted in Nepal. The research emphasizes that targeted policy measures, such as establishing clear regulatory frameworks and providing financial incentives, should be implemented to mitigate financial and market risks, which are perceived as the most critical by both public and private sectors. These measures help ensure the sustainability of Waste-to-Energy projects by effectively addressing risks related to revenue fluctuations, operational inefficiencies, and supply chain disruptions. [4,11].

Government involvement, particularly through guarantees, can significantly impact the successful implementation of PPP projects by mitigating critical risk factors. This is especially relevant in contexts like China, where government guarantees can equitably allocate risks under specific political, economic, and social environments [2,9,17,19]. Furthermore, the development of comprehensive risk allocation frameworks, as suggested for Indian MSW projects, is vital. These frameworks stress the importance of appropriate policies, legislation, and government support in managing risks, including market and human factors, to minimize disputes and project failures [17,19].

Quantitative risk analysis and local development initiatives are also essential strategies. Employing quantitative risk analysis, such as Monte Carlo simulations, helps in understanding financial implications and optimizing project financing. Encouraging project companies to develop local technology and equipment and maintain close contact with residents can mitigate operational risks. This approach supports both public and private sectors in training professional personnel and engaging with the community, which is crucial for managing social and operational risks effectively, as seen in China's WTE projects. These strategies collectively contribute to better management of financial and market risks in emerging economies' PPP WTE projects [9,11,17,18,20].

Table 5. The strategies for managing financial and market risks

Strategies	Author(s)	Results
Policy Implementation	Ghimirea et al. 2024; Liu et al. 2018	Understanding stakeholders' risk perceptions is crucial for protecting investments in PPP WTE projects, there is a need of policy measures to mitigate financial and market risks.
Government Guarantees	Xu et al. 2015; Wang & Zhang, 2017; Sun et al. 2017; Dolla & Laishram, 2021	Proper adoption of government guarantees can mitigate critical risk factors in PPP projects, equitably allocating risks within specific political, economic, and social contexts like China.

Risk Allocation Frameworks	Xu et al. 2015; Dolla & Laishram, 2021	Developing comprehensive risk allocation frameworks is crucial, as illustrated in India, where managing MSW project risks requires mitigation through appropriate policies, legislation, and support.
Quantitative Risk Analysis	Yaghubi et al. 2023; Liu et al. 2018	In projects using the Build-Operate-Transfer (BOT) model, quantitative risk analysis, such as Monte Carlo simulations, is important. This approach helps in understanding the financial implications of risks and optimizing project financing.
Local Technology Development and Equipment Management	Sun et al. 2017; Dolla & Laishram, 2021; Gad et al. 2023	Encouraging project companies to develop local technology and equipment, regularly check equipment use, and monitor emissions can mitigate operational risks.

4 Conclusion

The integration of private sector expertise and investment in PPP offers a promising way to tackle the complex challenges in WTE projects, such as technical, financial, environmental, and socio-political issues. Despite these benefits, these projects face significant risks that threaten their viability and sustainability. The review emphasizes the importance of thoroughly understanding these risk dynamics and using advanced risk assessment models to effectively mitigate them.

Various risk assessment methods show significant progress in understanding the complexities of these risks in PPP WTE projects. Traditional methods often fall short because they rely heavily on subjective judgments and fail to dynamically incorporate new data. However, innovative methods like the 2-Dimension Linguistic Environment and Cloud Model, Bayesian Analytics, and Hybrid Weight Methods provide more sophisticated and accurate risk assessments. These advanced methods allow for better decision-making by analyzing qualitative information more precisely, ultimately developing strong risk mitigation strategies crucial for the success of PPP WTE projects.

The different perspectives on risk among stakeholders further complicate the PPP WTE projects. Government bodies, the public, and private entities each have unique risk perceptions shaped by their roles and interests. Governments focus on regulatory compliance and social stability, the public is concerned with environmental and health impacts, and private stakeholders prioritize financial viability and operational efficiency. Addressing these varied concerns requires collaboration, trust, transparency, and effective communication among all parties. Aligning these efforts with comprehensive policy frameworks and technological innovations helps manage risks better, ensuring the successful and sustainable implementation of PPP WTE projects in emerging economies.

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References

1. Y. Wu, J Clean, Prod **183** (2018)
2. L. Wang and X. Zhang, International Journal of Architecture, Engineering and Construction, **6** (2017)

3. B. Kitchenham, *Guidelines for performing systematic literature reviews in software Engineering* (Software Engineering Group, School of Computer Science and Mathematics, Keele University, Keele, UK, 2007)
4. M. Ghimire, Energy for Sustainable Development **79** (2024)
5. W. P. Utama, A. Wibowo, D. Y. Jumas, E. Rita, M. Peli, and Yulcherlina, IOP Conf Ser Mater Sci Eng, **930** (2020)
6. X. Jie and Y. Jie, International Journal of Natural Resources and Environmental Studies, **9** (2024)
7. K. Wang, T. Zheng, K. Liu, and Y. Du, Social Network (to be published)
8. X. Zhang and L. Wang, International Journal of Architecture, Engineering and Construction, **7** (2018)
9. C. Sun, C. Cui, and Y. Liu, *Critical risk identification for PPP waste-to-energy incineration projects in china: a multiple case study*, in Proceedings Prefabricated Buildings, Industrialized Construction, and Public-Private Partnerships (American Society of Civil Engineers (ASCE), ICCREM, 10-12 November 2017, Guangzhou, China (2017)
10. C. Cui, C. Sun, Y. Liu, X. Jiang, and Q. Chen, Energy Science & Engineering, **20** (2020)
11. Y. Liu, Advances in Civil Engineering, **11** (2018)
12. M. Cheng, Construction and Architectural Management, **30** (2023)
13. L. Wang, Journal of Management in Engineering **34** (2018)
14. C. Luo, Sustain Cities Soc **74** (2021)
15. G. Cao, C. Guo, and H. Li, Sustainability*, **14** (2022)
16. N. A. Gad, HBRC Journal **20**, 829 (2024)
17. T. Dolla and B. Laishram, J Clean Prod **284** (2021)
18. N. A. Gad, K. El-Dash, T. M. Attia, and S. A. Dokhan, *Waste to energy (WTE) public-private partnership (PPP) projects: risk consideration and technologies*, in Proceedings Conference: 4th International conference Sustainable Construction and Project Management, ICSCPM, 19-21 December 2023, Egypt (2023)
19. Y. Xu, A. P. C. Chan, B. Xia, Q. K. Qian, Y. Liu, and Y. Peng, Appl Energy, **158** (2015)
20. D. Yaghubi, Complexity, **28** (2023)